TRANSPORT OF AMMONIUM- AND NITRATE-NITROGEN IN SURFACE RUNOFF FROM PASTURE AS INFLUENCED BY UREA APPLICATION*

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(Received September 8, 1982; revised November 11, 1982)

Abstract. The effect of a surface application of urea on the transport of N in surface runoff from permanent pasture in New Zealand was investigated under natural rainfall conditions. Maximum concentrations of NH_4–N(3.6 mg l^{-1}) and NO_3–N(4.5 mg l^{-1}) in surface runoff were attained 3 and 1 week, respectively, following urea application (60 kg N ha^{-1}). Amounts of NH_4–N, NO_3–N, and total N transported in surface runoff from unfertilized (1.58, 0.52, and 4.73 kg ha^{-1} yr^{-1}, respectively) and fertilized pasture (1.74, 1.09, and 8.96 kg ha^{-1} yr^{-1}) were less than inputs in precipitation (2.09, 3.63, and 10.9 kg ha^{-1} yr^{-1}), respectively. Amounts of NH_4–N, NO_3–N, and total N transported in surface runoff were only 0.3, 1.0, and 7.1% of that applied. The mean annual concentration of NH_4–N (0.9 mg l^{-1}) in surface runoff from unfertilized pasture was above the recommended levels for drinking water (0.5 mg l^{-1}) and the mean concentration of NO_3–N (0.5 mg l^{-1}) was greater than levels associated with accelerated eutrophication (0.3 mg l^{-1}). The practicality of attaining or maintaining N concentrations in surface runoff from fertilized agricultural land below recommended levels is questioned.

1. Introduction

The transport of N in surface water from agricultural watersheds has been associated with the accelerated eutrophication of natural waters (Makenthun, 1965; Vollenweider, 1968; Keeney, 1973). From a study of the biological productivity of several Wisconsin lakes, Sawyer (1947) suggested that if inorganic N concentration exceeded 0.3 mg l^{-1}, nuisance algal growth may be stimulated. It seems unlikely, however, that N will become limiting in a lake, due to inputs from precipitation and fixation by blue-green algae. Even so, interest has been directed towards the ammonium (NH_4–N) and nitrate (NO_3–N) content of surface waters, as accumulations can be hazardous to human health. Thus, the U.S. EPA (1972) recommended that NH_4–N and NO_3–N levels in potable water not exceed 0.5 and 10 mg l^{-1}, respectively.

Several studies have reported an increased transport of N in surface runoff following fertilizer N application to cropped watersheds (Schuman *et al.*, 1973; Klausner *et al.*, 1974). When 448 kg N ha^{-1} (80% as anhydrous ammonia and 20% as NH_4NO_3) was knifed to a depth of 25 to 35 cm in three corn-cropped watersheds in Iowa, Alberts *et al.* (1978) observed that an average of 1% of N applied was lost in surface runoff annually.

* Research by the Faculty of Agric. and Hortic. Sciences, Massey Univ., Palmerston North, supported by research grants from the Ministry of Agric. and Fisheries and the Dept. of Scientific and Industrial Res., New Zealand.

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Water, Air, and Soil Pollution **20** (1983) 425–430. 0049–6979/83/0204–0425$00.90.

Of this, 92% was particulate N, most of which was organic (80%). Although NO_3–N concentration did not exceed 10 mg l^{-1} (average annual flow weighted concentrations ranged from 1.1 to 3.9 mg l^{-1}), NH_4–N frequently exceeded 0.5 mg l^{-1} (average annual flow weighted concentrations ranged from 0.3 to 1.8 mg l^{-1}).

Less information is available on the loss of fertilizer N in surface runoff from pasture. Kilmer *et al.* (1974) noted that 6 to 10% of surface applied NH_4NO_3 was lost in surface runoff and base flow from 2 grassed watersheds in N. Carolina with slopes of 35 to 40%. The average annual NO_3–N concentration for the 4 yr study was 0.2 and 0.3 mg l^{-1} for NH_4–N and 1.2 and 3.9 mg l^{-1} for NO_3–N with fertilizer applications of 112 and 448 kg N ha^{-1}, respectively. Similar losses of TN (3.0 and 8.2% of applied urea, 224 kg ha^{-1} yr^{-1}) were measured by Moe *et al.* (1968) from a sloping (13%) silt loam under fescue-sod using simulated rainfall. Thus, appreciable losses of N in surface runoff can occur following urea application, although little published information is available on the losses resulting from urea additions to pasture under natural rainfall.

This paper reports on an investigation of the effect of a urea application on the transport of NH_4–N and NO_3–N in surface runoff from permanent pasture under natural rainfall.

2. Materials and Methods

The duplicate surface-runoff plots used in the study were established on undrained permanent pasture (6°30′ slope) on Tokomaru silt loam (a fragiaqualf). The design of the plots has been discussed previously (Sharpley and Syers, 1976). The plots were fenced to prevent access by animals and pasture height was controlled by mowing.

Twelve storm events were monitored to determine the uniformity of the two plots before urea was added. Urea which had been passed through a 100-mesh sieve was broadcast as evently as possible by hand, at a rate of 60 kg N ha^{-1}, to one of the plots at the end of July 1977. The second plot was used as an unfertilized control.

Surface runoff samples were collected as described by Sharpley *et al.* (1976) and analyses for N forms were carried out using a Technicon Autoanalysis system. Ammonium (NH_4–N) and NO_3–N were determined on filtered (< 0.45 μm) samples using the Berthelot reaction (Technicon Autoanalyser II, Industrial Method No. 98–70 W, USEPA, 1979), and automated Griess-Ilosvay method following reduction by cadmium (Hendrikson and Selmer-Olsen, 1970), respectively. Total Kjeldahl N (TKN) was determined after an automated Kjeldahl digestion of an unfiltered sample (Terry, 1966), with total N (TN) being calculated from the sum of NO_3–N and TKN.

The mean concentrations of NH_4–N and NO_3–N in each storm event were calculated from data for total loadings of N forms and total flow in each event. In addition, the total loss of NH_4–N, NO_3–N, and TN from the plots was calculated.

3. Results

The mean concentrations of NH_4–N and NO_3–N of individual surface runoff events (calculated from total loadings and total flow) from both plots were similar before the

application of urea (Figures 1 and 2, respectively). A four-fold increase in the mean concentration of NH_4–N in surface runoff was observed several days following urea application. A maximum value of 3.6 mg l^{-1} was attained three weeks after application (Figure 1). The effect was not sustained, however, with the mean NH_4–N concentration returning to the pre-fertilizer level (0.9 mg l^{-1}) seven weeks after application. The concentrations of NH_4–N from the unfertilized plot remained essentially constant during the period of surface runoff (Figure 1).

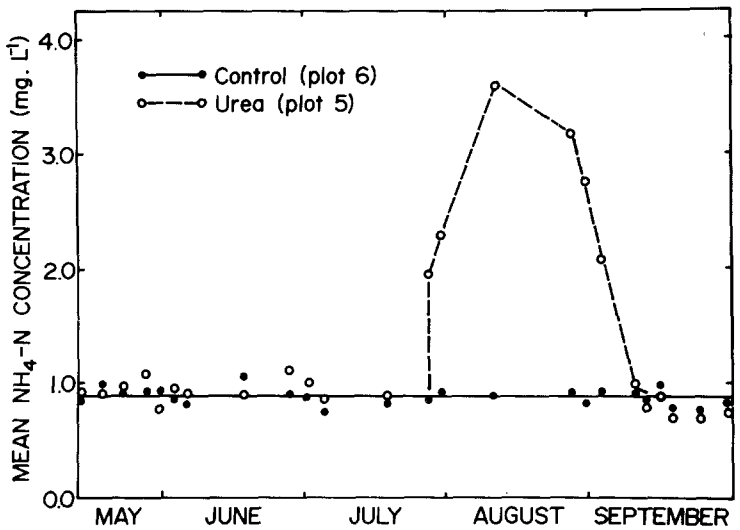

Fig. 1. Mean NH_4–N concentrations of individual surface runoff events before and after the application of urea in late July.

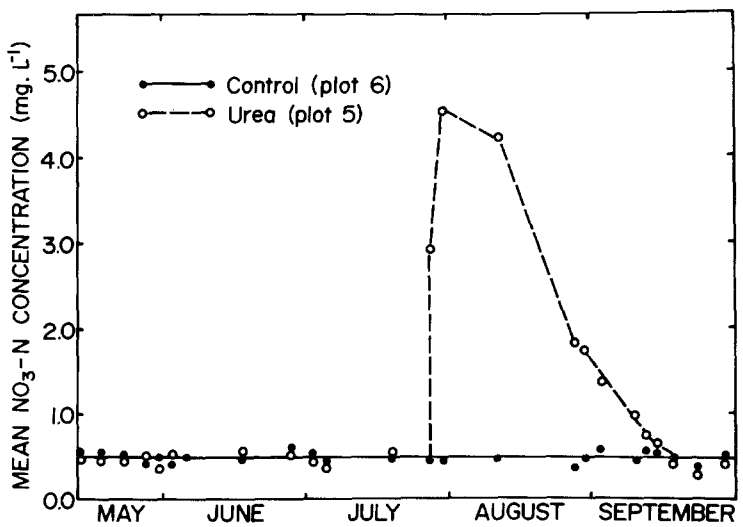

Fig. 2. Mean NO_3–N concentrations of individual surface runoff events before and after the application of urea in late July.

The increase in the mean NO_3–N concentrations following urea application was more dramatic (Figure 2). Within one week of application a nine-fold increase in NO_3–N concentration was measured, reaching a maximum value of 4.5 mg l^{-1}. Subsequently, the concentration of NO_3–N steadily decreased, reaching the pre-fertilizer level (0.5 mg l^{-1}) seven weeks after application (Figure 2). The concentration of NO_3–N in surface runoff from the unfertilized plot remained essentially constant during the period of surface runoff (Figure 2).

The concentrations of NH_4–N, NO_3–N, and TN in precipitation at the study site were measured at frequent intervals during 1977; these were observed to have relatively constant mean values of 0.23, 0.40, and 1.20 mg l^{-1}, respectively. It was subsequently calculated from the annual precipitation (910 mm in 1977) that 2.09, 3.63, and 10.9 kg ha^{-1} yr^{-1} of NH_4–N, NO_3–N, and TN, respectively, were added to the surface runoff plots in precipitation during the year of study.

The amounts of N forms transported in surface runoff during 1977 from the unfertilized and fertilized plots are presented in Table I. Although urea application resulted in only a small increase in the transport of NH_4–N (0.16 kg ha^{-1} yr^{-1}), an approximately two-fold increase in the amount of NO_3–N (0.57 kg ha^{-1} yr^{-1}) and TN (4.23 kg ha^{-1} yr^{-1}) was measured (Table I). The proportion of fertilizer N transported in surface runoff as NH_4–N, NO_3–N, and TN (corrected for soil losses) was 0.3, 1.0, and 7.1%, respectively. It is apparent, therefore, that the major proportion of the fertilizer N was transported in forms other than dissolved inorganic N.

TABLE I

Amount of N forms transported in surface runoff from fertilized and unfertilized pasture

Plot	Amount of N transported as			Percent of fertilizer N transported as[a]		
	NH_4–N	NO_3–N	TN	NH_4–N	NO_3–N	TN
	kg ha^{-1} yr^{-1}			%		
Fertilized plot	1.74	1.09	8.96	0.3	1.0	7.1
Unfertilized plot	1.58	0.52	4.76	–	–	–

[a] Corrected for data from unfertilized plot.

4. Discussion

The annual amounts of NH_4–N, NO_3–N, and TN added to the surface runoff plots in precipitation (2.01, 3.63, and 10.9 kg ha^{-1} yr^{-1}, respectively), were greater than those transported in surface runoff from both the fertilized and unfertilized plots (Table I). A similar situation was observed by Taylor *et al.* (1971) and Schuman and Burwell (1974) for cropped watersheds in Ohio and Iowa, respectively, in which the surface runoff discharge of N accounted for 20% of that input in precipitation. Surface runoff losses of inorganic N from unfertilized native prairie in Minnesota, accounted for an even smaller proportion (3%) of that input in precipitation (Timmons and Holt, 1977). In

the present study these differences can be accounted for by precipitation that did not cause surface runoff, adsorption of NH_4–N by soil material, and diffusion of NO_3–N into the soil profile. For example, the amounts of NH_4–N and NO_3–N added in precipitation which resulted directly in surface runoff (207 mm) were 0.48 and 0.83 kg ha^{-1}, respectively. When these values are compared with the amounts lost in surface runoff (Table I), it is apparent that while there is an enrichment of NH_4–N, vegetation and surface soil act as nutrient sinks for NO_3–N in precipitation.

Urea is water soluble and once in contact with moist surface soil is rapidly hydrolyzed to NH_4–N, which can be chemisorbed by micaceous clay minerals present in many soils (Brown and Bartholomew, 1962). In well aerated and warm soils, microbial activity will rapidly oxidize NH_4–N to NO_3–N (Harmsen and Kolenbrander, 1965). Consequently, soil conditions and time interval between urea application and the first precipitation event are important in determining the amount of urea converted to NH_4–N and NO_3–N and thus, the forms of N transported in surface runoff.

The small amount of fertilizer N transported in surface runoff (Table I), indicates that a large proportion of the applied urea was carried into the soil with the first increment of rain, away from the zone of removal by surface runoff. In addition, a greater proportion of TN was transported as NH_4–N (19%) compared to NO_3–N (12%). This difference suggests that cool soil temperatures and high soil water contents during the winter months restricted the conversion of NH_4–N to NO_3–N. Nitrate–N formed may also be rapidly leached into the soil profile.

Particulate N, defined here as TN-dissolved inorganic N, accounted for 56% of the TN transported from the unfertilized plot. This is a higher proportion of TN than that found by Burwell *et al.* (1975) and Timmons and Holt (1977) from unfertilized hay (2%) and prairie (33%), respectively. The contribution of particulate N to TN loss from the fertilized plot (68%) is also greater than that (51%) from fertilized pasture (168 kg N ha^{-1} yr^{-1} added) measured by Schuman *et al.* (1973).

Although the loss of fertilizer N in surface runoff was not agronomically important, mean concentrations of NH_4–N in runoff from unfertilized pasture (0.9 mg l^{-1}, Figure 1) were consistently higher than that recommended as the upper limit in drinking water (0.5 mg l^{-1}). In addition, NO_3–N concentrations (0.5 mg l^{-1}, Figure 2) were consistently higher than the critical values associated with accelerated eutrophication (0.3 mg l^{-1}). A similar situation was reported by Timmons and Holt (1977) where the mean annual flow-weighted concentration of inorganic N (NH_4–N and NO_3–N) in surface runoff from unfertilized native prairie was 1.3 mg l^{-1}, with a maximum value of 13.6 mg l^{-1} observed during the 5-yr study. Consequently, it appears to be unrealistic to attempt to attain or maintain NH_4–N or NO_3–N concentrations in surface runoff from fertilized agricultural land, below the recommended values.

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